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Ecoregion based attribution analysis of the influence of several fire danger indices on the amount of burned area at a global scale by means of pseudo transfer entropy

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Abstract

Understanding the current fire-climate relationships is of utmost importance in order to assess the potential impacts that projected climate may exert in the near future. However, the many factors involved in fire activity often prevent a proper attribution of the observed variability. Unlike the many previous correlative studies, here we address this problem using a 'causality' measure known as “pseudo transfer entropy” (pTE), relating three widely used fire danger indices to the global observed burned areas (namely the Canadian Fire Weather Index, the Fire Danger Index from the Australian McArthur Mark 5 Rating System and the Burning Index from the U.S. Forest Service National Fire-Danger Rating System). The study has been performed at an spatial aggregation level defined by the RESOLVE ecoregions, attending to their homogeneous fuel and climatic properties, and considering different spatial and temporal aggregation statistics (mean, 90th percentile, 95th percentile and sum).

We present an open, web-based interactive tool to explore and compare the results derived from the causality of these different fire danger indices with the observed burned area. Our results unveil some consistent patterns and three main conclusions can be drawn: 1) in the overall, all indices exhibit a similar performance in explaining observed burned areas, although regional differences may justify the selection of one index over another in regional studies, 2) the aggregation method used at the ecoregion level affects the causality results, with higher percentiles being better explained by pTE than the mean state and 3) the interactive tool designed may serve as a valuable method of intercomparison and analysis for the vulnerability and impact assessment community involved in fire research.

1. Introduction

Fire is an integral earth system process whose causes are complex (Pausas 2021), often difficult to disentangle, and largely dependent on the scale of analysis. Climate is one of the most important factors affecting fire regimes globally (Bedia 2015; Abatzoglou 2018). Understanding the current fire-climate relationships is of utmost importance in order to assess the potential impacts that projected climate may exert in the near future. However, the many factors involved in fire activity often prevent a proper attribution of the observed variability. Unlike the many previous correlative studies, here we address this problem using a 'causality' measure, in particular “pseudo transfer entropy” (pTE), relating three widely used fire danger indices (the Fire Weather Index from the Canadian Forest Service Fire Weather Index Rating System, the Fire Danger Index from the Australian McArthur Mark 5 Rating System and the Burning Index from the U.S. Forest Service National Fire-Danger Rating System) with global observed burned area records at a monthly scale in the last 20 years. Furthermore, we perform an intercomparison of these fire danger indices taking as spatial reference for the analysis the main terrestrial ecoregions.

2. Data collection

To perform this study, three different datasets have been taken into consideration.

2.1. Fire danger indices

The Copernicus Climate Data Store (CDS) catalogue entry named as "Fire danger indices historical data from the Copernicus Emergency Management Service" [ECMWF 2019] offers historical –1979 to present– information for a set of indices related to fire danger. These indicators are retrieved in a regular latitude-longitude grid which covers the entire globe (180ºW to 180ºE, 90ºS to 90ºN) with a spatial resolution of 0.25º and a daily temporal resolution. From this CDS catalogue entry, data for 3 variables was downloaded: the Fire Weather Index (FWI) from the Canadian Forest Service Fire Weather Index Rating System, the Fire Danger Index (FDI) from the Australian McArthur Mark 5 Rating System and the Burning Index (BI) from the U.S. Forest Service National Fire-Danger Rating System.

2.2. Fire burned area from satellite observations

We have used monthly data of Burned Area (BA) at 0.25◦ resolution from the "Fire burned area from 2001 to present derived from satellite observations" database (C3S 2019a; C3S 2019b) which is publicly available through the Copernicus Climate Data Store (https://cds.climate.copernicus.eu/cdsapp#!/home) as part of Copernicus, the European Union's Earth Observation Programme managed by the European Commission (https://www.copernicus.eu/en). The BA data used are derived through the analysis of reflectance changes from the medium resolution sensors Terra MODIS and Sentinel-3 OLCI, helped by the use of MODIS thermal information. The algorithms used are adapted to the native data from these sensors to produce an homogeneous gridded dataset of global coverage containing monthly data of BA at the grid scale, extending the database to the present.

2.3. RESOLVE Ecoregions dataset (2017)

RESOLVE Biodiversity and Wildlife Solutions provides access to this dataset containing information about 846 in-land ecoregions which depict an overall representation of our living planet (Dinerstein 2017). There is an online visor showing the above mentioned ecoregions: https://ecoregions.appspot.com/

3. Data pre-processing

The process to clean and homogenise the raw data –described in section 2– can be divided in the following tasks (schematized in Figure 1):

Despite having the same spatial resolution (0.25º), the fire danger indices data needed to be regridded to the burned area observations grid due to the fact that their meshes presented some differences. Afterwards, the data is temporally aggregated to the same temporal resolution: 1 Month. Therefore, the fire danger indicators are converted from daily to monthly data and the burned area observations remain in a monthly resolution.

As a last step, the ecoregion's metadata is used to perform a spatial aggregation on both the fire danger indices and the burned area observations.

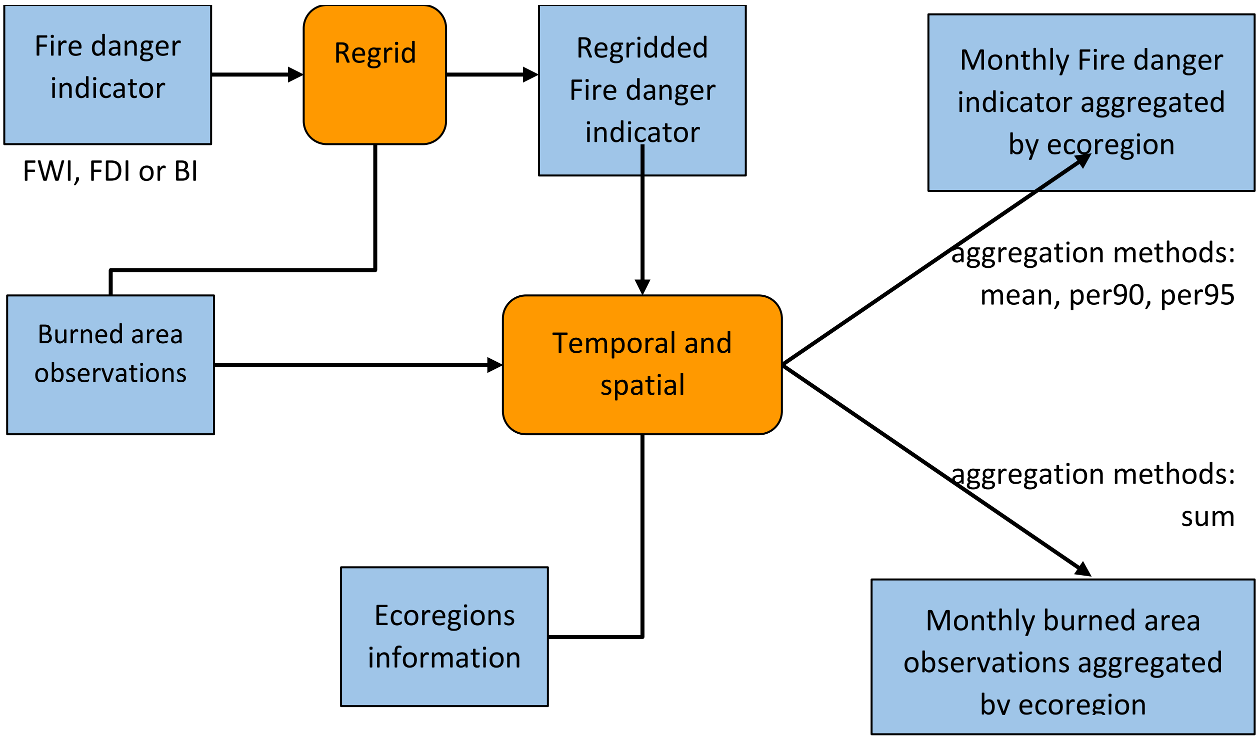

Figure 1- Data pre-processing scheme where the orange boxes represent tasks guided by an algorithm and blue boxes represent data that is used as input/output for the orange boxes.

The aggregation methods used remain constant in both temporal and spatial aggregation algorithms. As established in Table 1, the observed burned area was computed by the sum in order to have the total amount of area burned on time and space. However, the fire danger indices had a different approach and were computed using several statistical options such as the mean, the 90th percentile and the 95th percentile. Other aggregation methods such as the 99th percentile and the maximum were considered, but they presented a lower number of ecoregions with significant results on the causality measure.

Table 1. Combination of variable - aggregation method which were taken into consideration (green).

	MEAN	PERCENTILE 90	PERCENTILE 95	SUM
FWI				
FDI				
BI				
BURNED AREA				

As a consequence, there will be 10 different variables after the preprocessing task (+10 significance test results) for a total number of 693 ecoregions. This number is lower than the total number defined by the RESOLVE dataset due to the following specific facts: 1) some ecoregions do not have enough extent to perform the temporal and spatial aggregation over them –no grid points inside them–, 2) only terrestrial information was provided by both the fire danger indices and the burned area observations, and 3) there are ecoregions with no presence of fire in their surface.

4. Methodology

Once the monthly data is computed, an analysis of the causality from fire danger indices to the fire burned area is performed using a recent fast and effective metric called pseudo transfer entropy (pTE) (Silini 2021). Given two time series X and Y, we say that X causes Y, if the information contained in the past X, in conjunction with the information contained in the past of Y, can predict the future values of Y, better than the past of Y alone. This means that a fire danger index contains predictive skill on the observed burned area, if a significant pTE from the former to the latter is found. We compute the pTE between the monthly indices, using an embedding size of 2 and a time lag of 1. The embedding size is found by modelling the burned area time series as an autoregressive model.

Once the pTE between fire danger indices and burned area are computed, we have to account for their significance. From the original series we create 100 Iterative Amplitude Adjusted Fourier Transform (IAAFT) surrogates, preserving both the spectra and amplitude distributions, and we compute the pTE between them. The quantiles of the resulting pTE distribution, allow to define significance thresholds. In this study we consider a pTE value above the quantile 90 as significant.

5. Results and discussion

In the context of the research project, a web-app has been designed as a framework to visualise the causality measurement by means of pTE of the different combinations between the set of fire danger indices and the chosen aggregation methods with the total burned area: https://showcase.predictia.es/global-fwi-causality. The aggregation method –as well as the fire danger index– can be chosen on the right side panel. This tool allows the user to browse both the spatial and temporal characteristics of the different types of data. In this way, the user can study the spatial distribution of the causality of the different fire indices (Figure 2), but can also carry out much more in-depth investigations at the ecoregion level (for instance, the Italian Sclerophyllous And Semi-Deciduous Forests), having access to other features such as static data (Figure 3) the analysis of aggregated time series (Figure 4), scatter plot relating the value of the index to the burned area (Figure 5), and a heatmap which compares the index-aggregation method combinations with the burned area on an annual basis (Figure 6).

Some important conclusions can be derived from the web application. Overall, there is not a fire danger index (FWI, FDI or BI) that works globally better since all of them exhibit a similar performance. However, it makes really sense to use some of them over others depending on the ecoregion of interest when performing a local study. Moreover, all three indices follow similar patterns on how the significant ecoregions are distributed because most of them are located in three different main areas: over the boreal strip (Canada, Rusia, Greenland, among others), East-Asia and the Oceanic region, and the centre of Africa –where most of the worldwide area burned is located–.

The use of various aggregation methods allows the analysis of causality depending on whether more intermediate values of fire danger indices or more characteristic values of the extremes of these variables have been taken for the ecoregions of interest. Although there are more ecoregions with significant results when considering the mean value of the fire danger metric (FWI: 298, FDI: 281 and BI: 260) rather than, for instance, the 95th percentile (FWI: 269, FDI: 225 and BI: 240), it seems –as shown in the web-app– that the larger ecoregions are more affected by the extremes than ecoregions with a lower surface area.

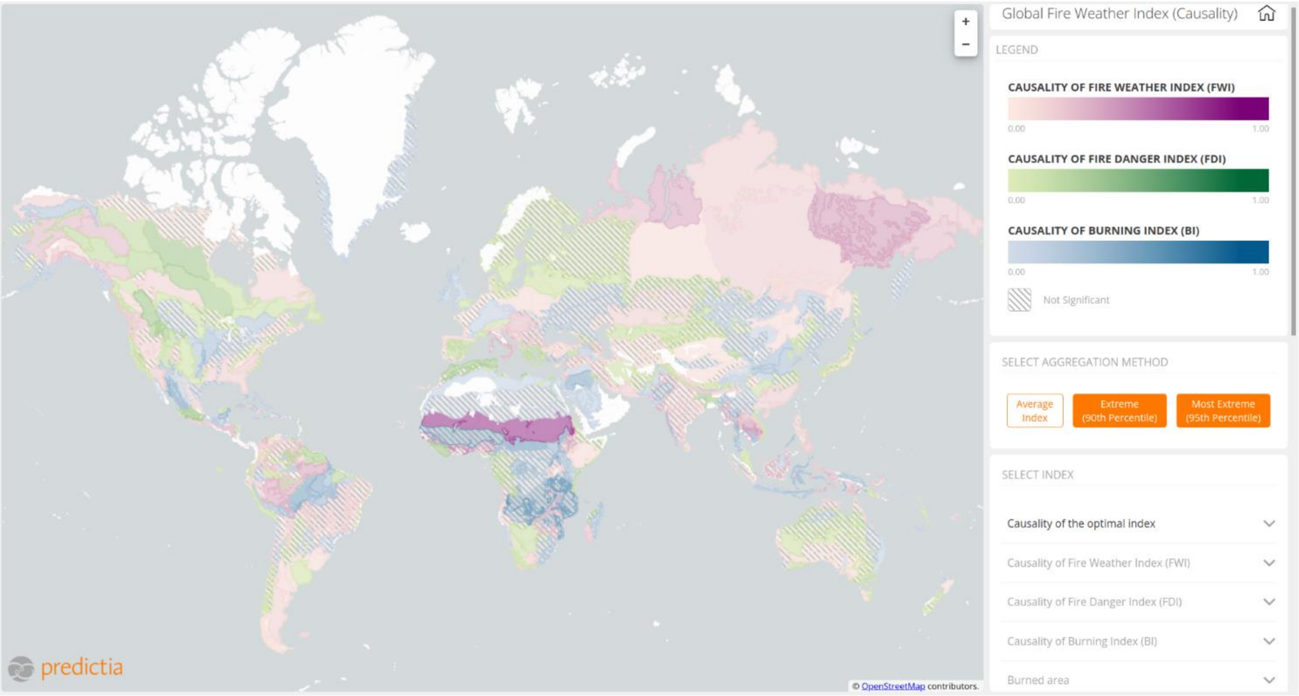

Figure 2- Home page of the web application designed to facilitate access to the processed data. At the left side, the ecoregion map with the 693 ecoregions available during the study. At the right side, there is a panel that acts as a selector to choose the different variables and aggregation methods available.

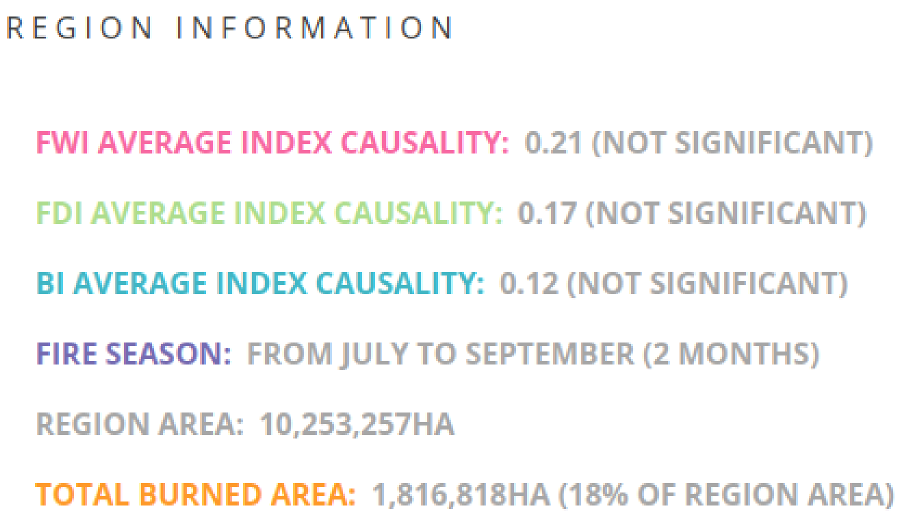

Figure 3- Example of ecoregion static information for the "Italian Sclerophyllous And Semi-Deciduous Forests" ecoregion. This static information contains: the causality of the different indices (FWI, FDI and BI) aggregated by a given aggregation method (95th percentile in this case), the fire season and its length, the ecoregion area and the corresponding total area burned.

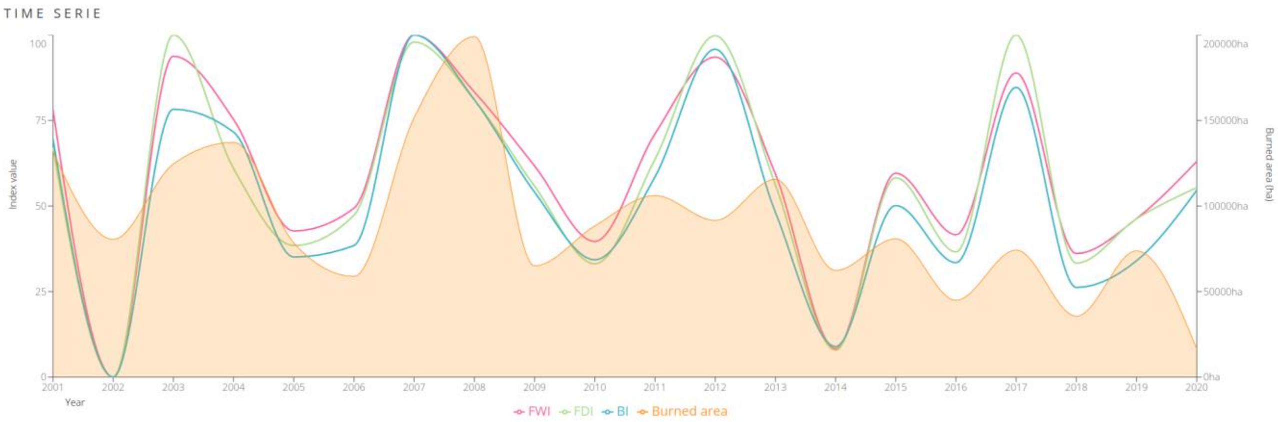

Figure 4- Example of time-serie showing the annual data for different indices (FWI, FDI and BI) aggregated by a given aggregation method (95th percentile in this case) and the total burned area for the "Italian Sclerophyllous And Semi-Deciduous Forests" ecoregion.

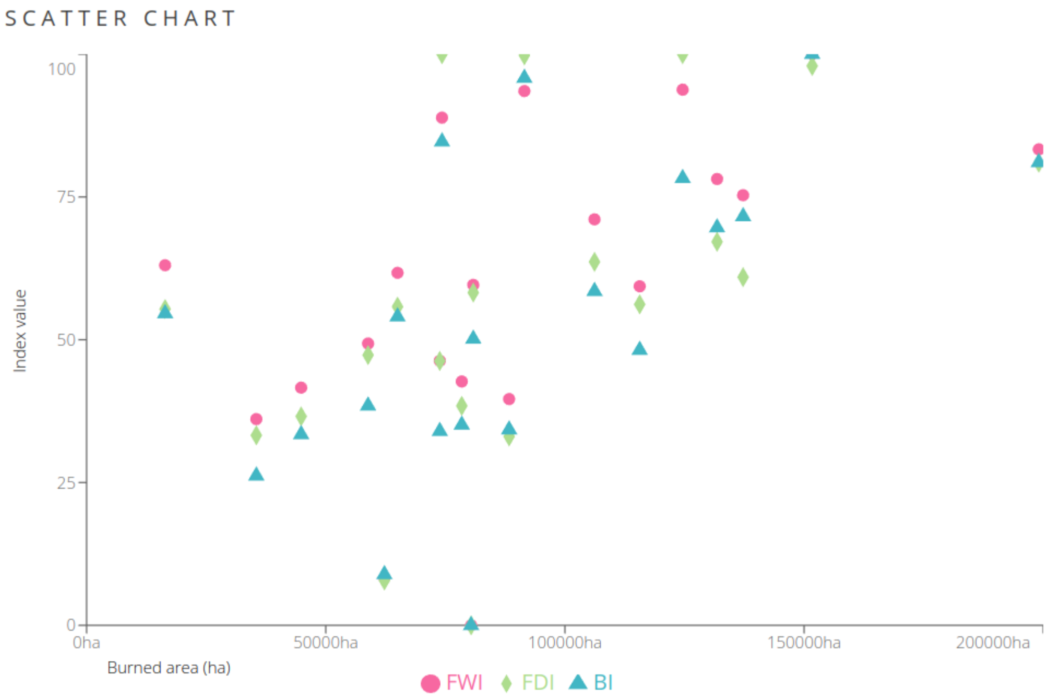

Figure 5- Example of scatter chart showing the relation between the different indices (FWI, FDI and BI) aggregated by a given aggregation method (95th percentile in this case) and the total burned area for the "Italian Sclerophyllous And Semi-Deciduous Forests" ecoregion.

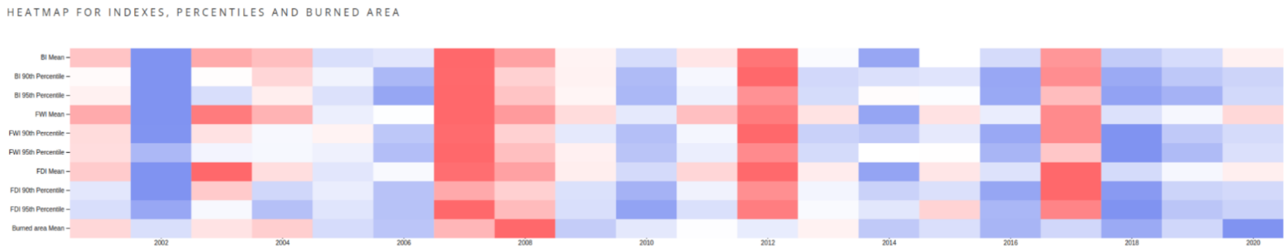

Figure 6- Example of quantile based stripes showing the annual characterisation in comparison with the entire period for all the different combinations of indices (FWI, FDI and BI) and aggregation methods (mean, per90, per95) and the total burned area for the "Italian Sclerophyllous And Semi-Deciduous Forests" ecoregion. From blue to red, it indicates the quantile to which the data belongs: lower, mid-lower, mid-upper, upper.

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